

Multi-slice spiral CT 3-dimensional reconstruction technique to treat multi-segmental degenerative spinal stenosis with traumatic instability of lower cervical spine

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Objective: To study the feasibility of multi-slice spiral computed tomography (MSCT) 3-dimensional reconstruction technique in assisting cervical pedicle screw fixation (PSF) and double-door laminoplasty to treat multi-segmental degenerative spinal stenosis with traumatic instability (MDSTI) of lower cervical spine.

Methods: From September 2006 to August 2007, PSF combined with double-door laminoplasty was performed in 9 patients with MDSTI of lower cervical spine. MSCT 3-dimensional reconstruction techniques, including volume rendering (VR) and multi-planar reconstruction (MPR), were used to assist preoperative diagnosis and measurement to guide the procedure. MPR was performed after operation. In coronal view, the degree of screw perforation was measured precisely and the different positions of pedicle screws were divided into three grades according to Richter's method. In axial view, the canal sagittal diameter and transverse area of every laminoplasty level were measured.

Results: Nine patients with MDSTI of lower cervical spine underwent PSF (total 44 screws). According to the classification of Richter, 72.7% (32/44) was in Grade 1 and 27.3% (12/44) was in Grade 2. No screw perforation occurred in Grade 3 and no screw revision was done for misplacement.

No iatrogenic damage was observed. Double-door laminoplasty was performed in total 42 volumes. The post-operative sagittal diameter and transverse area of cervical spinal canal were significantly increased ($P < 0.05$). The confidence intervals of mean increased ratio were 23.43%–40.65% in sagittal diameter and 23.18%–42.07% in transverse area. Six months after laminoplasty, based on MSCT axial view, complete union between “open door” and allograft bone was obtained in 76.19% of volumes (32/42), and allograft bone was absorbed partly in 23.81% (10/42). A solid union in bilateral gutters was achieved in all cases. They were followed up from 6 months to 1 year (mean 7.8 months). Post-operative neural function recovery in two cases improved 2 ASIA grade, 5 cases improved 1 grade and 2 cases remained the same as preoperative grade. No cases had lower ASIA grade.

Conclusion: Assisted with MSCT 3-dimensional reconstruction technique, PSF combined with double-door laminoplasty can be performed more safely and effectively to treat patients with MDSTI of lower cervical spine.

Key words: *Cervical vertebrae; Spinal stenosis; Tomography, spiral computed; Surgical fixation devices*

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Cervical spinal canal stenosis is usually caused by degenerative processes in the soft tissue and bone structures of the cervical spine, which

are present in approximately 50% of the population at 50 years of age.¹ The cervical myelopathy at different degrees resulted from spinal canal stenosis may occur in most cases. For the remaining limited space of spinal canal, minor translation or rotation in a traumatic event can induce spinal cord compression or lower cervical spine injury, even lead to disastrous outcome such as severe neurologic deterioration, tetraparesis or high quadriplegia.^{2,3} Because of low energy injury, some patients only present symptoms but have no positive findings of fractures or dislocations in plain X-ray and CT. Additionally, posttraumatic symptoms can be easily confused with neurologic symptoms caused by cervical spinal canal stenosis. Therefore, it is difficult to

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make a correct diagnosis. Currently, cervical pedicle screw fixation (PSF) is applied to treat traumatic instability and double-door laminoplasty is used to treat cervical spinal canal stenosis. Both obtain satisfactory results, which have been well described in literatures.⁴⁻⁹ However, there are few reports about PSF combined with double-door laminoplasty to treat multi-segmental degenerative spinal stenosis with traumatic instability (MDSTI) in lower cervical spine. Meanwhile, due to the complex structures of cervical spine, the potential risks of iatrogenic dural injury or neurovascular structure damage during the decompression and instrumentation remains a major concern.¹⁰⁻¹² Therefore, cervical surgeons have been taking efforts to improve the accuracy of PSF, reduce complications, stabilize subaxial spine, decompress spinal cord and evaluate therapeutic effect quantitatively.

The purpose of this study was to demonstrate the efficacy of multi-slice spiral computerized tomography (MSCT) 3-dimensional reconstruction technique to assist PSF and double-door laminoplasty in the treatment of MDSTI of lower cervical spine in order to optimize preoperative plan, guide the operation and evaluate clinical outcomes.

METHODS

Patients

Between September 2006 and August 2007, assisted by MSCT 3-dimensional reconstruction technique for diagnosis, measurement and evaluation, 9 patients (6 males and 3 females) with MDSTI of the lower cervical spine underwent PSF combined with double-door laminoplasty in our institution. The posterior pedicle screw implantation combined with spiral CT 3-dimensional reconstruction was conducted in unstable cervical segments and totally 44 screws were inserted. The double-door technique was employed in all patients. The cervical laminoplasty (totally 42 volumes) included C₃-C₇ in 6 patients, and C₃-C₆ in 3. The time from injury to surgery ranged from 16 hours to 21 days.

The patients were 55.44 years old on average (range: 47-67 years). There were 5 cases of falling injuries, 3 vehicle accident injuries and 1 beating injury. The lower cervical spinal injuries included posterior column injuries in 5 patients, facet injuries in 2 and anterior column injuries in 2. Traumatic instable levels of cervical

spine included C₄-C₅ in 2 cases, C₄-C₆ in 1 case, C₅-C₆ in 2 cases, C₆-C₇ in 3 cases and C₆-T₁ in 1 case.

The thorough history about cervical myelopathy had been questioned in emergency room. The headache or neck pain of various frequency and severity occurred in all cases before injury. In addition, the patients mainly complained about balance and gait, arm pain and weakness in the upper or lower extremities, but they had no bowel or bladder incontinence before injury.

The neurologic examination included the evaluation of sensory, motor and reflex functions. The initial neurologic status of the spinal cord-injured patient should be recorded using the American Spinal Cord Injury Association (ASIA) impairment scale¹³, including 2 with Grade A, 3 with Grade B, and 4 with Grade C.

Radiography, MRI and MSCT 3-dimensional reconstruction

Three radiographic views of entire cervical spine, including anteroposterior, lateral and open-mouth odontoid views, were taken to confirm cervical trauma in all cases. It was necessary to take bilateral oblique views to support the initial diagnosis, but a deliberative attitude should be adopted for taking dynamic flexion-extension views in cases of subaxial spine injury.

Preoperative MRI (GE, 1.5T, America) was recommended to demonstrate multi-segmental cervical canal stenosis due to congenital small canal space, broad disk herniations, ligamentous hypertrophy and cord compression extended to at least three disk levels. As well as increased T₂ signal in damaged spinal cord, intervertebral disk and soft tissues were visualized (Fig.1).

A MSCT 3-dimensional reconstruction system (Philips, MX8000 MSCT, America) was used for the precise surgical planning before operation, at 200 mAs/120kv, 3.0-mm section thickness and 0.625-mm reconstruction increment. The volume rendering (VR) and multi-planar reconstructions (MPR) were applied to reconstruct 3-dimensional images. The decompressive regions of spinal canal had been confirmed. In the MPR image, the best dimensions and angles of screws insertion were simulated to provide the reference to the procedure. Individual parameters for inserting screws were precisely measured at interested region by axial, sagittal and coronal MPR, respectively. The dimensions

and angles of insertion were automatically calculated using the software in CT workstation (Fig.2).



Fig.1. In preoperative MRI, cervical cord was compressed by multiple degenerative disks and spinal canal presented a small space.

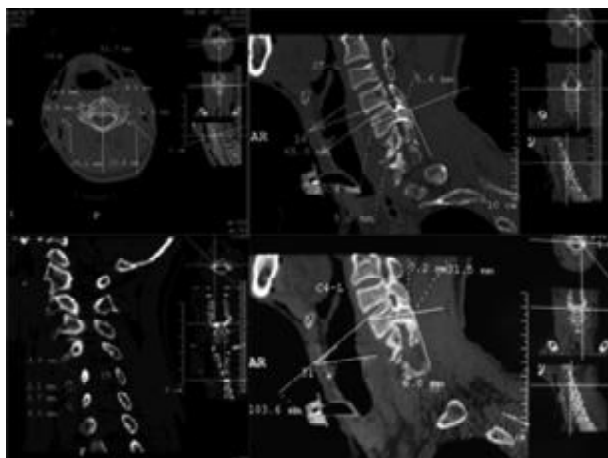


Fig. 2. The size of pedicle, the entry point and angles of pedicle screw insertion were measured using MPR technique.

The measured dimensions and angles were listed as follows: (1) pedicle axial length (a distance between the posterior point and the anterior point of the pedicle axis projection), (2) pedicle horizontal angle (an angle between the pedicle axis and a line perpendicular to the posterior vertebral body cortex), (3) lateral mass rim distance (a distance between the lateral mass rim and the posterior point of pedicle axis projection), (4) cervical spinal canal sagittal diameter (a distance between the midpoint in posterior vertebral body cortex and the base of spinous process), (5) cervical spinal canal area (the inner edge of the spinal canal), (6) pedicle sagittal angle (an angle between the longitudinal axis of pedicle and a line parallel to the inferior facet), (7) inferior facet rim distance (a distance between the infe-

rior facet rim and the posterior point of pedicle longitudinal axis projection), (8) pedicle width (mediolateral diameter of the pedicle isthmus), and (9) pedicle height (superoinferior diameter of pedicle isthmus).

Surgical procedure

A patient was placed in the prone position after general anesthesia. Fixation of the head traction was done with tongs attached to an adjustable head fixation device in a slightly flexed position (10° - 20°) so that the cervical spine was paralleled to the floor. The position must be calibrated using the levelling instrument repeatedly. C-arm fluoroscopy was placed in front of head to obtain the views.

A straight posterior midline skin incision from the cervicocranium to the cervicothoracic junction was made to expose the posterior vertebral elements in the lateral margin of the facet joints. Deformity of subaxial spine was corrected by traction. Based on the lateral mass rim distance and inferior facet rim distance, entry points were confirmed manually using a digital sliding caliper, and a 3.5-mm burr was used to create posterior cortical breach in the entry point, approximately 5 mm in depth. The trajectory of pedicle screws was drilled using a 2.7 mm drill bit and a small handheld protector, approximately 15-20 mm in depth. The horizontal direction and cephalocaudal angulation of pedicle screws insertion were adjusted manually according to preoperative CT measurements by a goniometer, respectively. Anteroposterior and lateral fluoroscopy views were taken to confirm the accurate trajectory in the procedure. According to the measured data of pedicle axis length, width and height before operation, the suitable titanium screws were selected and inserted. Finally, following the screw fixation, fluoroscopy was utilized again to make sure whether the screws were inserted in accurate position and the curve of cervical spine returned to normal.

At the junction of the lamina and facet joint, a high-speed drill was used to make two gutters on two sides while preserving the ventral cortex well, which acted as two hinges. A thin-bladed Kerrison rongeur was used to remove ligamentum flavum at the cranial and caudal ends of the intended laminar expansion, usually at the C_2/C_3 and C_7/T_1 interspaces. Spinous processes of C_3-C_6 or C_3-C_7 were then split sagittally at midline using a high-speed saw on the surface. The depth of slitting

was close to the ventral cortex. The remaining cortex was removed by Kerrison rongeur. When the operation at all levels were finished, the spinous processes and laminae were carefully opened like windows using flat forceps and fingers. A spacer of allograft bone was inserted between the slitting spinous processes and stabilized with silk threads and other spacers were inserted at other levels in the same way. Sometimes screws were implanted into bilateral pedicles to act as anchors. The silk threads were bond to anchor screw heads to prevent the loosening caused by absorbed allograft bone and keep the "door" open. Finally, operative time and blood loss were recorded.

Radiographic assessment

Postoperative spiral CT scanning and 3-dimensional reconstruction were used to evaluate the efficacy and accuracy, and coronal MPR was mainly utilized to precisely measure the degree of screws perforation. According to the position, pedicle screws were divided into three grades according to Richter's method,¹⁴ when cortical integrity was questionable, the screws were categorized in the inferior grade (Fig.3). Richter's grades were as follows: Grade 1, without pedicle perforation or with pedicle perforation <1 mm; Grade 2, pedicle perforation >1 mm without the need for screw revision; and Grade 3, pedicle perforation >1 mm with the need for screw revision due to irritation or injury of roots or the myelon or due to reduced biomechanical stability.

The increase in sagittal diameter and canal area of every laminoplasty level were determined by axial MPR and the data were obtained directly using the measurement tool in the software attached to CT workstation (Fig.4).

Postoperative MRI confirmed the degree of spinal canal decompression and spinal cord recovery (Fig. 5).

Statistical analysis

Clinical results of recovery were assessed through the ASIA impairment scale.¹³ The software SPSS 11.0 for Windows (SPSS Inc.) was used for statistical analysis. Data were expressed as mean \pm SD. Correlation between preoperative and postoperative spinal canal sagittal diameter and spinal canal area were assessed by Pearson's *t*-pair text. $P < 0.05$ was considered as statistical significance.



Fig.3. C₇ left pedicle screw had 0.6 mm perforation in lateral mass but no neurologic, vascular or visceral injury related to screws was found. The other pedicle screws had no pedicle perforation or perforation less than 1 mm.

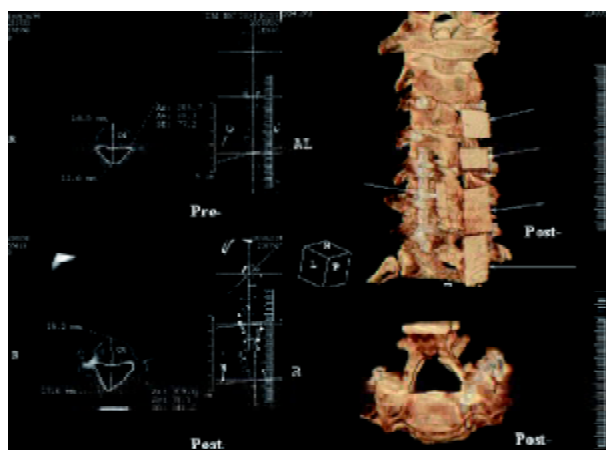


Fig.4. The pre- and post-operative data of sagittal diameter and canal area of C₄ were determined by axial MPR. Postoperative VR 3-dimensional images visualized the procedure.

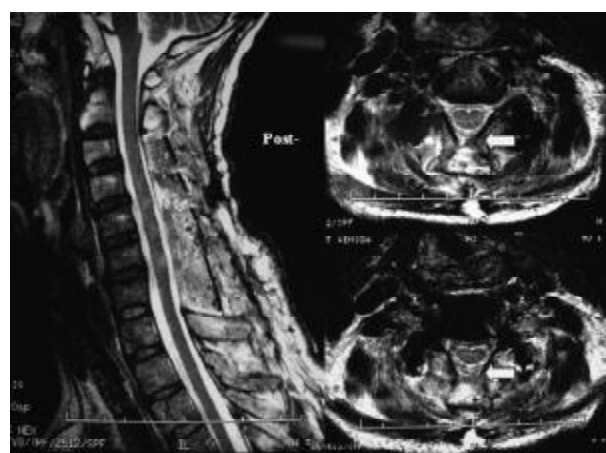


Fig.5. By postoperative MRI, spinal canal was decompressed. The transverse area and sagittal diameter of spinal canal were increased obviously.

RESULTS

Demographics

Nine patients with multilevel cervical spinal canal stenosis associated with traumatic instability underwent PSF (totally 44 screws) and double-door cervical laminoplasty (totally 42 volumes). No case was found to have a dural defect during the procedure and no damage was increased from iatrogenic elements. The successful rates of screw placement were 72.7% (32/44) in Grade 1 and 27.3% (12/44) in Grade 2, respectively. No manifestations of vertebral artery injury were observed in 12 cases of Grade 2. No screw perforation in Grade 3 or no screw misplacement was found (Table 1).

The sagittal diameter and transverse area of cervical canal were (12.98 ± 1.80) mm and (234.11 ± 31.51) mm² before operation and (17.03 ± 1.84) mm and (308.30 ± 33.72) mm² after operation, respectively (Table 2). *t*-pair test showed that the difference between preoperative and postoperative sagittal diameter ($t=11.576$, $P<0.0001$) and the difference between preoperative and postop-

erative transverse area ($t=8.217$, $P<0.0001$) were significant ($P<0.05$). The confidence intervals of mean increased ratio were 23.43%-40.65% and 23.18%-42.07%, respectively.

The postoperative cervical spinal canal sagittal diameter and transverse area were significantly increased ($P<0.05$). The confidence intervals of mean increase ratio were 23.43%-40.65% in former and 23.18%-42.07% in later. According to the MPR format of laminoplasty performed at postoperative 6 months, 76.19% of volumes (32/42) had the complete union between "open door" and allograft bone and 23.81% (10/42) had the allograft bone absorbed partly. Bilateral gutters obtained solid union in all volumns.

Clinical results

All cases were followed up from 6 months to 1 year (mean 7.8 months). Two cases increased 2 ASIA grades, 5 cases increased 1 grade, and 2 cases still remained the same grade as preoperative one. No case's grade became lower after operation (Table 2).

Table 1. The clinical data of pedicle screw fixation

Patient No.	Traumatic instable levels	Inserting segments	Pedicle screws	Perforation in Grade 1	Perforation in Grade 2
1	C ₅ -C ₆	2	4	3	1
2	C ₄ -C ₅ , C ₅ -C ₆	3	6	4	2
3	C ₅ -C ₆ , C ₆ -C ₇	5	10	9	1
4	C ₆ -C ₇	2	4	3	1
5	C ₆ -C ₇	2	4	3	1
6	C ₅ -C ₆	2	4	2	2
7	C ₆ -C ₇	2	4	3	1
8	C ₄ -C ₅	2	4	3	1
9	C ₄ -C ₅	2	4	2	2

Table 2. The clinical data of double-door laminoplasty and ASIA scores

Patient No.	Degenerative stenosis levels	Double door laminoplasty segments	Preoperative ASIA scores	Postoperative ASIA scores
1	C ₂ -C ₃ -C ₇ T ₁	5	C	C
2	C ₂ -C ₃ -C ₆ -C ₇	4	A	B
3	C ₂ -C ₃ -C ₇ T ₁	5	B	D
4	C ₂ -C ₃ -C ₆ -C ₇	4	B	D
5	C ₂ -C ₃ -C ₇ T ₁	5	C	D
6	C ₂ -C ₃ -C ₆ -C ₇	4	A	B
7	C ₂ -C ₃ -C ₇ T ₁	5	C	D
8	C ₂ -C ₃ -C ₇ T ₁	5	B	B
9	C ₂ -C ₃ -C ₇ T ₁	5	C	D

DISCUSSION

Diagnosis of MDSTI

Cervical spondylosis is a common cause of degenerative canal stenosis, including spurs, transverse osseous ridges, disk herniations and ossification of the posterior longitudinal ligament. Cervical spondylosis contributes to spinal cord compression at one level or multiple levels. Spinal cord compression of at least three disk levels is considered as multilevel stenosis. Spondylosis combined with an inherent narrow spinal canal (Pavlov's ratio < 0.8)¹⁵ will increase the risk of cord compression with resultant myelopathy or radiculomyelopathy. The symptoms of cervical myelopathy usually include an alteration in balance and gait, pain in neck or arm, weakness in the upper or lower extremities, hyperreflexia and gross long-tract signs.

When the lower cervical spine injuries occur in the patients with multilevel degenerative canal stenosis, the risk of spinal cord injury will be increased, even minor forces applied to head and neck may result in disastrous outcomes in spinal cord. Some patients only present symptoms but have no positive findings of fractures or dislocations in plain X-ray and CT. Therefore, it is difficult to estimate traumatic instability.

Flexion-extension X-rays of the cervical spine is the "gold standard" for ligamentous instability in patients with cervical pain without radiographic evidence of fracture.¹⁶ However, the use of dynamic flexion-extension X-rays to assess stability and potential ligamentous injuries is controversial because it may cause the secondary spinal cord injuries in traumatic subaxial spine. The instability of lower cervical spinal cord can be assessed using White and Panjabi checklist¹⁷ and MRI with fat-suppression techniques. According to Holdsworth's two-column theory,¹⁸ stable injuries usually involve only one column and unstable injuries involve both columns. MRI will reveal the evidence of hemorrhage with its increased signal intensity in anterior or/and posterior columns of damaged region. Additionally the patient will be scored on the White and Panjabi checklist. If the sum of all values is no less than 5, the spine can be defined as clinically unstable.

Treatment of MDSTI

The treatment of MDSTI is to protect the spinal cord from additional trauma, decompress neurologic tissue,

create an environment for neurologic recovery and provide a long-term stable, painless cervical spine. The management involves immobilization, medical stabilization, restoration of spinal curve, spinal cord decompression and finally spinal stabilization.

Earlier spinal cord decompression and stabilization are effective to decrease the neurologic damage, but the medical complications associated with spinal cord injury and aging usually affect the earliest surgery intervention, especially poor respiratory function resulted from quadriplegia or paraplegia, so medical stabilization takes first priority before operation.

For the cases of myelopathy with diffuse multilevel canal stenosis, nearly normal lordosis and little neck pain, the posterior approach is recommended for less loss of motion, less bracing or no graft complication. Removal of the posterior elements will provide indirect decompression of spinal cord. As an improvement of laminectomy, laminoplasty may enlarge the spinal canal without removing the posterior bone elements, allow the posterior cervical musculature to reattach and minimize the chance of late kyphosis from laminectomy. Double-door laminoplasty have been described as an excellent procedure for multilevel cervical stenosis in literature (its advantages are listed in the following chapter).

Subaxial pedicle screw fixation is the only posterior technique that can provide two-column fixation of the cervical spine. The screws have greater pullout strength that can resist toggling from cyclic axial loading and supply long-term fixation in cases of anterior injury in which vertebral buttress is destroyed.¹⁹ Screw loosening with pseudarthrosis or loss of deformity reduction has not been reported with pedicle fixation.²⁰ If the posterior approach is adopted to stabilize subaxial spine, pedicle screw fixation has a significant advantage over other techniques. The bilateral entry point of pedicle screw insertion can provide enough space to perform double-door laminoplasty.

MSCT assisted surgery

Traditional cervical PSF such as Abumi's freehand method²¹ relies on rich clinic experiences to treat most patients. However, it has some disadvantages, such as limitation of vision, low precision, difficult instrument insertion, high screws penetration rates, and so on.

Following Abumi, PSF has been developed, which currently consists of three techniques including techniques depending on anatomical landmarks, techniques with exposure of the pedicle and computerized image-guided navigation systems. Despite the literature have described appealing clinical results about the application of those techniques, it is proved that PSF could provide a significantly higher stability compared with other posterior fixation techniques.²⁷⁻²⁹ However, the potential risk of neurologic, vascular and visceral injury related to screws insertion impels surgeon to reduce pedicle screw misplacement. In recent years, computer assisted orthopedic surgery technique seems to be a safe and accurate method,^{14,22} but it is difficult to extend in most institutions because of its expensive price, complex manipulation and increased surgical time.^{23,24} Moreover, the pedicle perforation rates is reported to be 18%-87.5% in cervical spine.^{25,26}

Spiral CT 3-dimensional reconstruction can obtain the intuitionistic high-quality 3-dimensional image. The damaged region and the internal anatomical relationship of cervical spine can be visualized by rotating the 3-dimensional VR image. If necessary, through the incising technique, the image of interested region can be separated so as to do single and dynamical observation and plan the surgical approaches. In addition, MPR technique can be used to stimulate the instrumentation and precisely measure the dimension and angles to guide the procedure.

In this study, the CT 3-dimensional reconstruction combined with radiography and MRI was applied in the diagnosis, preoperative design, guidance and evaluation of MDSTI. The accurate classification, detail revealing of anatomical structure, consummate preoperative regimen design and individual measurements could be carried out before surgery, especially the segments of anatomic variation and the blocked or minor cancellous core are visualized clearly. Basing on the measurement from preoperative CT 3-dimensional reconstruction, screw entry point, angle and size could be confirmed and intraoperative fluoroscopy can be used to monitor the drill trajectory. Once the entrance point and correct drill direction are set, surgeons can obtain the greater possibility of successful screw insertion and save more operative time. Therefore, with this technique, the surgeon can perform the procedure guided by the preoperative 3-dimensional "roadmap", but not merely

over rely on individual experience of hand sensitivity.

Open door laminoplasty

Anterior decompression with fusion or laminectomy have long been the two standard treatment methods for cervical compressive myelopathy.³⁰⁻³³ The anterior procedure consists of anterior corpectomy or discectomy with resection of uncovertebral joint followed by anterior bone graft.^{34,35} Several issues should be noted in this procedure, including graft complications, late instability of motion segments adjacent to fused level, vocal cord paralysis, esophageal perforation, and potential danger of damaging vertebral artery.^{36,37} Because of these problems, the anterior procedure is mainly used for single or two-level diseases.

The posterior procedure is preferred for multilevel diseases with the exception of preexisting cervical kyphosis.³⁸ However, conventional laminectomy also has several postoperative complications such as kyphosis, swan neck deformity, and segmental instability.³⁸⁻⁴⁷ To prevent the complications after laminectomy, Hirabayashi et al.⁴⁸ introduced "expansive open door laminoplasty" in 1978. Since then, many modifications of the procedure have been reported,⁴⁹⁻⁵² in which one of the most epochal procedures is "double door laminoplasty" introduced by Kurokawa in 1982.⁵³ In this procedure, spinal canal enlargement is achieved by sagittal splitting of the spinous process and graft bones are inserted between the split spinous processes. The procedure is characterized by symmetric configuration of reconstructed posterior elements that theoretically allows symmetric expansion of spinal cord, and closed ring configuration of neural arch for each segment through insertion of bone graft, which allows wide access to the spinal cord. So this procedure is widely accepted.

In this study, we used PSF in unstable level to ensure the stability and prevent potential cervical kyphosis. Meanwhile, double-door laminoplasty was performed to enlarge the spinal canal and decrease the limit of cervical motion resulted by anterior approach, which obtained satisfactory results. Therefore, it is a reasonable choice for treatment of multilevel cervical spinal canal stenosis associated with traumatic instability.

In conclusion, assisted by MSCT 3-dimensional reconstruction technique, the combined PSF with double-

door laminoplasty is a safe and effective procedure to treat patients with MDSTI.

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